Chapter 12

High Voltage Trigger Generators for Pulse Power Systems

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Solid state switch based high voltage trigger generators are used widely for the controlled switching and repetitive operation of the spark gap switches in pulse power systems. Spark gap switch is the most popular, durable and reliable switch which is being used for several decades in pulse power systems consistently. Although spark gap switches breakdown phenomena is dependent on several physical parameters such as surface condition, gaseous medium in between gaps, pressure of the medium, spacing between electrodes etc., and exactly at what voltage and time the switch will bridge, is highly statistical prediction, but their voltage and current handling capability is unmatched. In this scenario high voltage trigger generator provides a controlled and repetitive operation capability to these switches. One another very important application of high voltage trigger generator is, synchronized operation of more than one spark gap switches in parallel combination. In electromagnetic welding, rail gun and other pulse power applications where four-five or even more number of energy storage capacitors are needed to be discharged simultaneously in to load for enormous current of the order of mega ampere, it becomes necessary to synchronize multiple spark gap switches within a permissible range of jitter. Hence, a high voltage trigger generator having fast rate of rise of output voltage performs very crucial role.

12.1. High Voltage Trigger Generator Electrical Circuit and Working

An electrical circuit diagram with the schematic of triggering of a trigatron type spark gap switch is presented in Figure 12.1. Transformer T_1 step ups the 230VAC input to 415VAC and then rectified by a bridge rectifier containing diodes D_1, D_2, D_3 and D_4. Primary capacitor C_0 is charged through the primary winding of the pulse transformer T_2 and the resistors R_1 & R_2 are connected to both positive and negative sides to limit the initial charging current as well as isolation purpose. Once the capacitor C_0 is charged fully and the IGBT switch is triggered, C_0 start discharging through the IGBT and primary of T_2, here the direction of current in primary winding is opposite to that of charging current which help to de-saturate the magnetic core automatically. Corresponding to the primary voltage and turn ratio of the pulse transformer, a high voltage pulse is generated across the secondary which is feed to the trigger pin of the spark gap switch by keeping a decoupling capacitor in series at the both terminals of output. This high voltage pulse creates an initial spark between trigger pin and cathode results in breakdown of main channel between anode and cathode. Series combination of resistor Rs and capacitor Cs is connected across the IGBT switch as a snubber circuit to avoid development of any fast rising voltage surge across it. Capacitor C_1 and C_2 are called decoupling capacitor which blocks any possible flow of DC current through the secondary of pulse transformer.

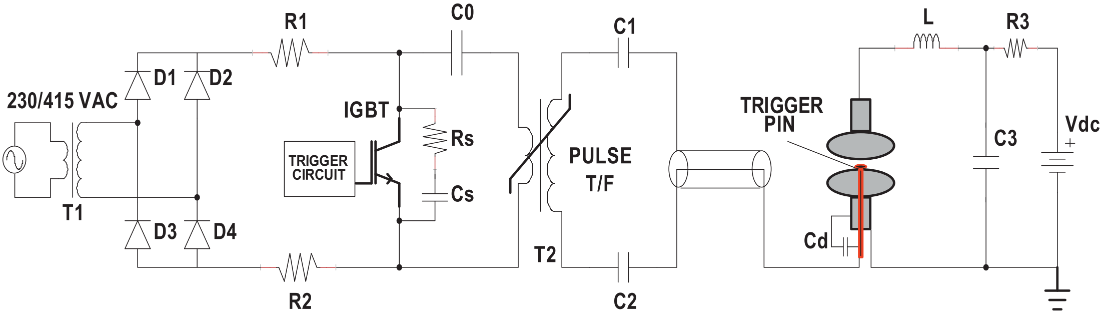


Figure 12.1. Electrical circuit & trigetron switch.

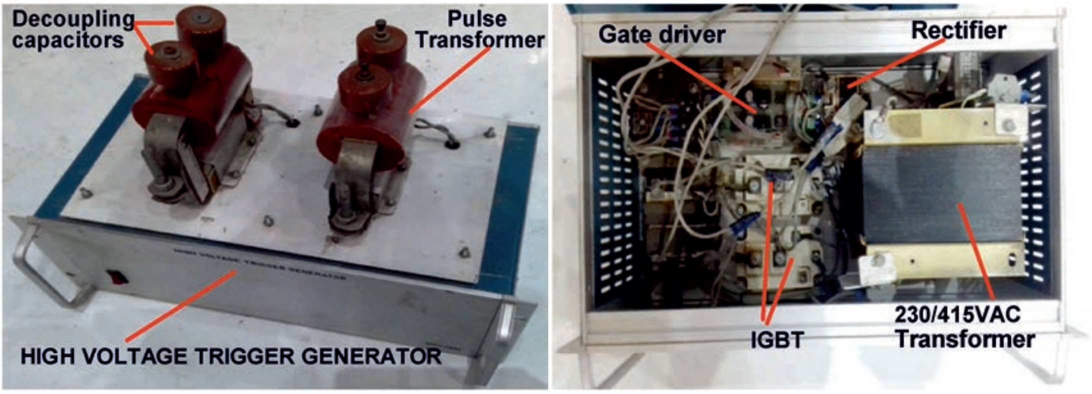


Figure 12.2. High voltage trigger generator with dual output.

12.2. Design Methodology

While designing a high voltage trigger generator there are several parameters which should be evaluated rigorously such as the selection of the components like rectifier, charging resistor, solid state switch and its protection, pulse transformer and primary capacitor. Pulse transformer is the most crucial part of all these and most of the design values will be influenced by this, however its design will not be discussed here. It will be selected on the basis of required output and available input voltage with transformation ratio k .

12.2.1. Primary Capacitor (C_p)

Starting the component selection from primary capacitor C_0, one should know that how much energy (U) is required to be deposited in the form of charge between spark gap electrodes and on the surface of cathode which comes from study of breakdown phenomena of gaseous medium through various experimentation and statistical analysis. Looking backward to the circuit operation, this amount of energy, U must be stored in the parasitic capacitance $C_{d,}$ formed between trigger pin and cathode.

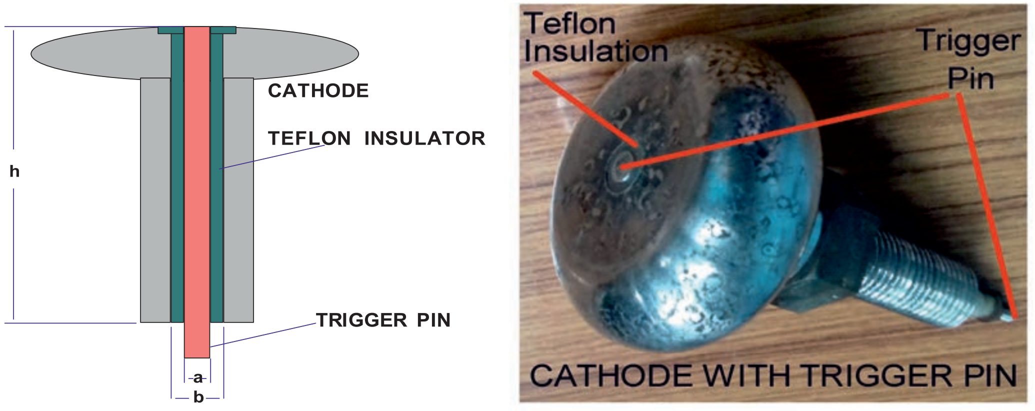
$$U = \frac{1}{2} C_d V_d^2 \qquad \text{Joule} \tag{12.1}$$

Where, V_d is required voltage across C_d for storing energy U Joule.

Parasitic capacitance, C_d can be evaluated or more precisely can be estimated using eq.(12.2) with reference to Figure 12.3(a).

$$C_d = \frac{2\pi \varepsilon_0 \varepsilon_r h}{\ln\left(\frac{b}{a}\right)} \qquad Farad \tag{12.2}$$

Where, ε_0 is permittivity of free space and ε_r is relative permittivity of insulating/dielectric material, h is length of the cylinder and a, b are inner and outer diameter of cylindrically formed capacitor. For the convenience of the reader, the most common type of triggering arrangement is discussed here and distributed capacitance is assumed in the cylindrical form, although in real case it can be of any other shape or size and designer has to go with the actual geometry.



(a) (b)

Figure 12.3. Cathode with axially inserted trigger pin.

Next step is to assume the capacitance C_d as load connected at secondary side and transfer it to the primary side of the pulse transformer, which is an energy balance criteria.

$$U = \frac{1}{2} C_d V_d^2 = \frac{1}{2} C_0 V_p^2$$
$$C_d V_d^2 = C_0 V_p^2$$
$$C_0 = C_d \left(\frac{V_d^2}{V_p^2} \right)$$

The quantity $\left(\frac{V_d^2}{V_p^2} \right)$ is nothing but the transformation ratio of the pulse transformer which will be denoted by k, then

$$C_0 = C_d k^2 \qquad (12.3)$$

Thus we reached at Eq. (12.3) which gives the value of C_0 with respect to C_d, but one thing which needed to be taken in account that the pulse transformer will not have unity coefficient of coupling because there is always some leaking of magnetic flux. Leakage inductance at primary side is the key factor which determines efficiency of energy transfer from primary to secondary as well as rate of rise of secondary output voltage. Therefore, C_0 must be added few extra capacitance C_{ex} to compensate the energy lost due to leakage inductance (magnetization losses will not be accounted here).

Hence, the required primary capacitance C_p will be

$$C_p = (C_0 + C_{ex}) \qquad (12.4)$$

When there is no leakage inductance then current in primary is given by the following relation, neglecting primary winding resistance.

$$I_p = \frac{V_p}{Z_p} \quad \text{and} \quad Z_p = \sqrt{\frac{L_p}{C_0}}$$

In order to maintain the same current in primary when there is a leakage inductance L_l taken in to account, one need to add extra capacitance C_{ex} at the primary side so that effect of leakage inductance on transformation ratio can be nullified. Let us do a little bit mathematics,

$$I_{p1} = \frac{V_p}{Z_{p1}} \quad \text{and} \quad I_{p2} = \frac{V_p}{Z_{p2}}$$

Where, I_{p1} is current without leakage inductance and I_{p2} current with leakage inductance. We can write,

$$\frac{V_p}{Z_{p1}} = \frac{V_p}{Z_{p2}} \qquad \text{when establishing, } I_{p1} = I_{p2}$$

$$Z_{p1} = Z_{p2} \qquad \text{or} \qquad \sqrt{\frac{L_p}{C_0}} = \sqrt{\frac{L_p + L_l}{C_0 + C_{ex}}}$$

$$C_{ex} = C_0 \, \frac{L_l}{L_p} \tag{12.5}$$

On substituting C_{ex} in to Eq. (12.4), we get

$$C_p = C_0 \left(1 + \frac{L_l}{L_p}\right) \tag{12.6}$$

Hence, one can go analytically or can measure directly the leakage inductance of primary winding by LCR meter and may find the value of required capacitance to be added with the help of Eq. (12.5).

12.2.2. Charging Resistor ($\mathbf{R_{ch}}$)

The charging resistor R_1 & R_2 should be selected in such a way that the charging current does not exceed current rating of charging power supply and power rating of these resistors should also be appropriate. Energy rating of the resistor can be find from Eq. (12.7),

$$U_{res} = \frac{1}{2} C_p V_p^2 \tag{12.7}$$

Figure 12.4. Typical resistors used for capacitor charging.

12.2.3. Solid State Switch and Its Switching

Switch is chosen according to the voltage and current at primary side of the pulse transformer. Generally IGBT switches are preferred as their voltage and current ratings are sufficient and they have fast switching characteristic. Higher than peak discharge current should be considered for the switch to be used. I_{peak} is given by the following relation,

$$I_{peak} = \frac{V_p}{\sqrt{\frac{L_p}{C_p}}} \tag{12.8}$$

Now, it is required to have a suitably designed RC snubber circuit to avoid fast rising voltage surge across the switch, as shown in Figure 12.1.

A standard or self-designed gate driver can be used for the triggering of solid state switch. One should always prefer optically isolated remote triggering, for the reason of safety of low voltage trigger pulse generating electronic circuit as well as the person operating it.

12.2.4. Decoupling Capacitors ($C_{decouple}$)

Selection of decoupling capacitors (C_1 & C_2) depends upon the DC voltage which should be decoupled while passing most of the energy to the parasitic capacitance C_d from pulse transformer. Withstanding voltage of decoupling capacitors should be twice or above of the applied DC voltage. Voltage across C_d, is given by,

$V_d = V_s \frac{C_{decouple}}{C_{decouple} + C_d}$ where, $C_{decouple} = \left(\frac{C_1 C_2}{C_1 + C_2}\right)$

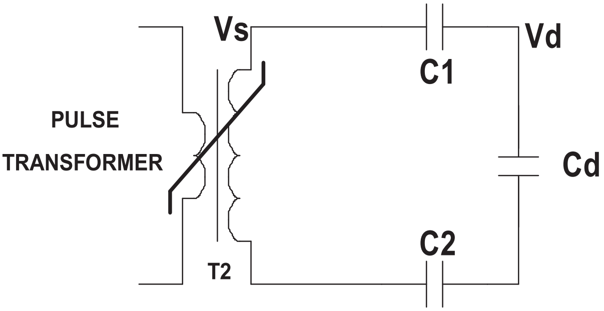


Figure 12.5. Voltage division between C_d and decoupling capacitors.

12.3. Effect of Leakage Inductance and Compensating Capacitance on Output

Leakage inductance of the primary winding of a pulse transformer plays key role for determining efficient energy transfer and rise time of output voltage. It is well studied that rise time of applied high voltage trigger pulse has great importance in fast switching as well as in synchronization of multiple parallel connected spark gap switches. Therefore, it becomes mandatory to minimize the leakage inductance during the design and manufacturing of pulse transformer, but it is also true that this unwanted quantity will never vanish completely and designers are left with the only choice to neutralize its effect by adding some extra capacitance or compensating capacitance. Effect of leakage inductance and compensating capacitance can be seen from Figure 12.6(a), 12.6(b), 12.6(c) and 12.6(d). When the leakage inductance is minimum then output voltage is maximum as in figure 12.6(c), on the other hand when leakage inductance is 25% output voltage decreases significantly given by Figure 12.6(a). Addition of compensating capacitance C_{ex}, neutralizes the effect of leakage inductance L_l up to an acceptable level and the output increases as shown in Figure 12.6(b) and 12.6(d). One another important conclusion from Figure 12.6(a) and 12.6(c), one can find that rise time of output is significantly affected by leakage inductance i.e. decreases with increasing L_l.

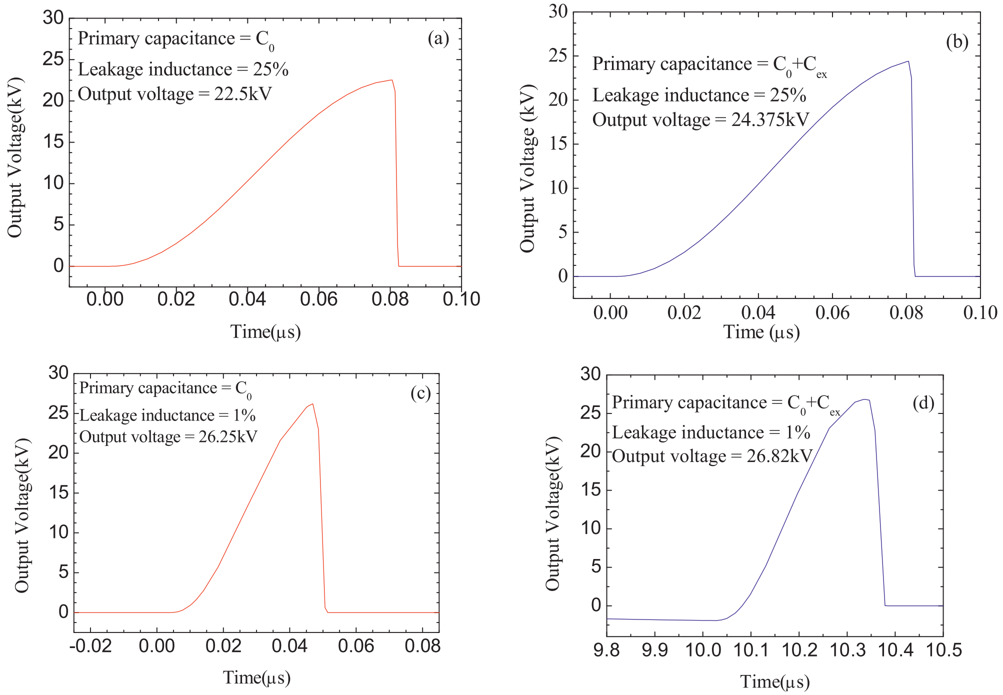


Figure 12.6. Effect of compensating capacitance on output when $L_l = 25\%$ (a) without and (b) with compensating capacitance, Effect of compensating capacitance on output when $L_l = 1\%$ (c) without and (d) with compensating capacitance.

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